Site Preparation and Classification

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FOREST CLEARCUTTING AND SITE PREPARATION ON A SALINE SOIL IN EAST TEXAS: IMPACTS ON WATER QUALITY

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Abstract—Three 0.02 hectare plot-watersheds were installed on a saline soil in the Davy Crockett National Forest near Apple Springs, Texas. Each plot was installed with an H-flume, FW-1 automatic water level recorder, Coshocton N-1 runoff sampler, and two storage tanks. One watershed was undisturbed forested and served a control, one was clearcut without any site-preparation, and the third was clearcut, V-blade sheared, windrowed, and vegetation regrowth was prevented for the first 2 years. A total of 274 storms were recorded during the four-year study period, 1989-1992. Average annual sediment losses for the study period were 55, 197, and 1,530 kilograms per hectare per year for the control, commercial clearcut, and sheared plots, respectively. These losses are about average for most studies conducted in East Texas and the Southeast and are well below average losses for all land uses in the Southeast. Sediment losses and surface runoff were significantly greater from the sheared plot-watershed than from the control and the commercial clearcut plots. Employing Wischmeier and Smith's (1978) long-term average R-value for the USLE overestimated annual sediment yield for the study period, while two shortcut models developed in the United States resulted in more accurate predictions and are good substitutes for the long-term R-value. Total losses in surface runoff of PO_4, NO_3, NO_2, TKN, K, Ca, Mg, Na, Al, Fe, Zn, and Cu were higher on the site-prepared plot watershed than the other two. Losses of PO_4, TKN, and NO_2 were higher on the commercial clearcut plot than the control. Losses were not high enough to adversely affect forest productivity. Concentrations of elements were generally below established USEPA surface water quality standards and were not high enough to adversely affect plant growth.

INTRODUCTION

Commercial clearcutting is the most common silvicultural system employed for the regeneration of upland forests in East Texas. Following harvest, sites are usually prepared for planting by mechanical techniques such as shearing, chopping, bedding, ripping or some combination of these activities. Concern has arisen regarding possible degradation of site productivity over time and possible degradation of water quality (USEPA 1993).

There are more than 120,000 hectares of somewhat poorly drained, upland saline soils in central East Texas (between Sam Rayburn Reservoir and Livingston Reservoir). These soils have high salt concentrations, low permeability, and are frequently saturated. Upland vegetation is predominately mixed pine/hardwood, with loblolly (*Pinus taeda*) and shortleaf (*Pinus echinata*) pine dominating the overstory. Conversion of these natural stands to plantations can be difficult, reporting as many as three attempts with no success in some areas. J-rooting and limited lateral root development at about 15 centimeters below the surface is frequently observed on theses sites. High mortality rates are thought to be the result of a rise in the water table following harvest, seedlings experiencing salt toxicities, nutrient imbalances, or some combination of these factors. Surface runoff from clearcut sites on these soils could negatively impact water quality as well.

This study was initiated in 1988 to examine the impacts of clearcutting and site preparation on sediment movement and water quality from a saline soil in East Texas. The results from the first two years were presented in Sayok and others (1993a and 1993b) on sediment and element movements and Chang and others (1992) on applications of the universal soil loss equation. Effects on soil properties were reported in Chang and others (1994). This report summarizes the results of all four years of data collection.

METHODS AND PROCEDURES

Study Area

This study was conducted during the water years 1989 through 1992 in the Davy Crockett National Forest near Apple Springs, Texas, about 200 kilometers north of Houston and 250 kilometers southeast of Dallas. The area is characterized by a humid subtropical climate with prevailing winds from a southerly direction. Precipitation is fairly evenly distributed throughout the year. Winter precipitation is associated with frontal activity while summer precipitation is dominated by convective storms of high intensity, low frequency and short duration. Precipitation during the study period was 1,119 millimeters, 1,236 millimeters, 1,295 millimeters, and 1,208 millimeters for the 1989, 1990, 1991, and 1992 water years (October-September), respectively. These amounts were much

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Table 1—Annual rainfall, surface runoff, and sediment losses for three forested conditions near Apple Springs, Texas for water years 1989-1992[a]

	Water Year				
Parameters	1989	1990	1991	1992	Average
Rainfall (Pt mm)	1,119	1,236	1,295	1,208	1,215
Number of Storms	63	55	77	79	69
Surface Runoff (Ro mm)					
Forested	14 A	68 A	31 A	9 A	31 A
Clearcut	60 B	107 B	59 A	38 A	66 B
Sheared	299 C	577 C	404 B	375 B	414 C
Runoff/Rainfall (Ro/Pt percent)					
Forested	1.2	5.5	2.4	0.8	2.5
Clearcut	5.4	8.6	4.5	3.1	5.4
Sheared	26.7	46.7	31.2	31.0	34.1
Sediment Loss (kg ha^{-1})					
Forested	56 A	72 A	33 AB	61 B	55 A
Clearcut	422 B	287 B	50 B	33 A	198 B
Sheared	2,374 C	2,916 C	725 A	116 B	1,533 C

[a] Different letters in a given year indicate that the means of all events are significantly different at $\alpha \leq 0.05$

higher than the normal (1951-1980) annual precipitation of 1,077 millimeters observed at the Lufkin Airport about 22 kilometers east of the study site.

The area is characterized by gently rolling topography with slopes averaging 2 to 10 percent. Severe erosion can occur on slopes above 2 percent. The soil of the study site is Fuller fine sandy loam, a member of the fine loamy siliceous, thermic family of Albic Glossic Natraqualfs. The salinity of these soils results from volcanic ash blown from the Cook Mountain Formation during the Eocene epoch and deposited on siltstones or mudstones. The area was inundated by ocean water and the volcanic ash was compacted. Silty materials were blown from the west and settled on the compacted ash.

Loblolly and shortleaf pines dominated the overstory with a mixture of post oak (*Quercus stellata*), red oak (*Quercus falcata*), white oak (*Quercus alba*), sweetgum (*Liquidambar styraciflua*), and hickories (*Carya* spp.). Merchantable

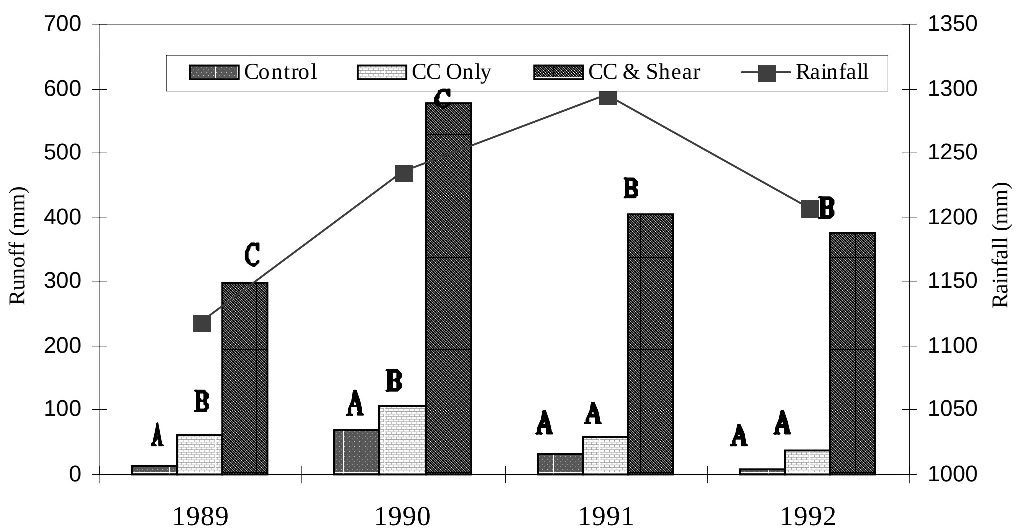

Figure 1—Surface runoff and rainfall by treatment and water year for Apple Springs, Texas

trees ranged from 30 to 55 years of age in 1988 with an average height of 28.5 meters, diameter at breast height of 25 centimeters, site index (50) of 27 meters, and basal area of 21.81 square meters per hectare.

Treatments

Three treatments were employed in this study: 1) undisturbed forest with full crown closure as a control, 2) commercial clearcut with all merchantable timber removed, other vegetation and logging debris left intact, and 3) commercial clearcut with all vegetation removed, stumps sheared with V-blade D6 crawler tractor, and all debris windrowed. Vegetation was prevented from regrowing by hand shearing with no soil disturbance for the first two years following treatment. To avoid potential edge effects, the distance from the sides of the plots to the surrounding stand was at least 30 meters. Harvesting was conducted on July 23-24, 1988 and site preparation on August 26, 1988. Due to budget constraints, treatments were not replicated.

Plot Watersheds and Data Analysis

Each plot was 0.02 hectares in size (9.14 meters by 22.13 meters) and was located in each treatment area to monitor surface runoff and soil and element losses generated by storm events. All plots were located within a 3.24 hectare area, with comparable environmental conditions regarding vegetation, soils, slope, and aspect. A plywood barrier 8 centimeters below and 7 centimeters above the ground bordered each plot. At the lower end of each plot an approach apron, a 15.4 centimeter H-flume, a stilling well with an FW-1 water level recorder, a Coshocton N-1 runoff sampler, and a storage tank were sequentially connected together. The Coshocton wheel diverted about 1 percent of the surface runoff into a small storage tank. The small tank was confined in a larger tank designed to accommodate surface runoff generated by 48-hour 50-year storms. Total soil loss from each storm runoff event was the sum of sediment deposited in the apron and approach section plus suspended sediment collected in the storage tank. Volumes of surface runoff were directly measured from the storage tank and also interpreted from the charts of the water-level recorders.

The volume of surface runoff generated from each runoff event was converted to depth. Samples were collected after each runoff event and were transported to the Stephen F. Austin State University Arthur Temple College of Forestry Forest Hydrology Laboratory for chemical analyses of 19 water quality parameters. Methods and procedures for water quality analyses were reported in Sayok (1991) and Sayok and others (1993b).

USEPA's (1986) water quality standards were used as a reference to evaluate surface runoff water quality conditions. Data failed to meet the assumption of normality for parametric statistical analyses. Therefore, the nonparametric Kruskall-Wallis test as described by Hollander and Wolfe (1999) and SAS Institute, Inc (1999) was employed to determine differences in concentrations among the three treatments. The Wilcoxon's rank sum procedure was used to evaluate multiple comparisons where the Kruskall-Wallis test found differences to be significant at $a \leq 0.05$.

The data were also stratified into summer- (May – October) and winter- (November – April) half years for testing seasonal effects on surface water quality. Seasonal differences were determined using the Wilcoxon's rank sum procedure.

RESULTS AND DISCUSSION

Rainfall and Runoff

Rainfall during the four year study period was considerably higher than the average rainfall (1951-1980) of 1,077 millimeters reported at the Lufkin Airport about 22 kilometers east of the study area (table 1). Highest precipitation occurred in water year 1991 with 218 millimeters or 20 percent more precipitation than normal.

Annual surface runoff generated from the plots varied considerably with treatment and by water year (table 1). Since all vegetation, stumps, and debris were removed and no regrowth of vegetation was allowed for the first two years, the sheared plot had the least transpiration and interception loss among the three plots. Furthermore, the soil was compacted by the heavy machinery, resulting in a decrease in infiltration rate and an increase in soil moisture content. Bulk densities were found to be greater following treatment (Chang and others 1994). This translated to more total surface runoff from the sheared plot and greater runoff efficiency. Average runoff as a percent of rainfall (Ro/Pt) for the four-year period was 34 on the sheared plot and only 3 and 5 on the control and commercial clearcut plots, respectively. The percent Ro/Pt ratio for the clearcut plot (5) was about the same as reported by two other East Texas studies: 6 in Cherokee County (Blackburn and others 1986) and 8 in Nacogdoches County (Chang and others 1982). However, percent Ro/Pt ratio for the sheared plot was higher (34) than values reported in Nacogdoches (29) and Cherokee (11) counties. Runoff as a percent of precipitation did not decline significantly on the sheared plot during the study period. Ro/Pt was 31 percent during year four, whereas it was 27 percent during year one. This may be due to the lower permeability and higher soil moisture content of the saline soil.

Using the Kruskall-Wallis test and Wilcoxon's rank sum, the sheared plot were found to be significantly different from the control at $a \leq 0.05$ for all four years (figure 1). During water years 1989 and 1990, all three plots were significantly different from one another. However, during water years 1991 and 1992, the commercial clearcut plot was not significantly different from the control plot (figure 1).

Sediment Losses

Annual Losses—Sediment losses were highly significant among treatments. First year sediment losses were 56, 422, 2,347 kilograms per hectare for the control, cleared, and sheared plots, respectively (table 1). Losses among plots were significantly different the second year following treatment as well. This difference is due to greater soil disturbance on the shear treatment, resulting in more exposed bare soil. By the third year, the control and cleared plots were no longer significantly different, although the losses of sediment on the sheared plot remained

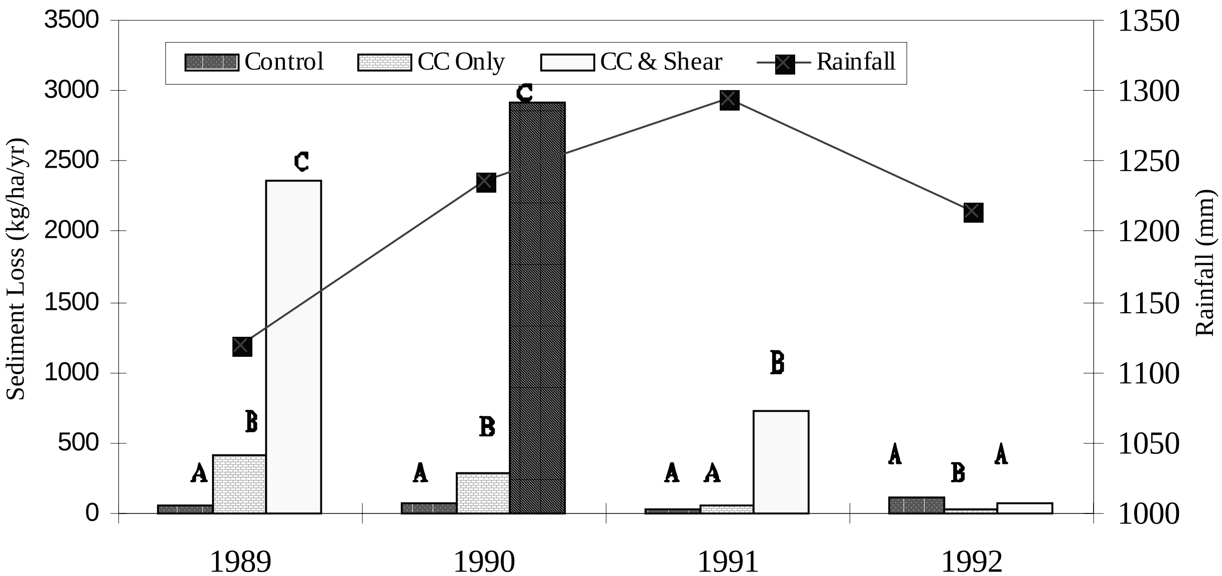

Figure 2—Sediment loss and rainfall by treatment and water year for Apple Springs, Texas.

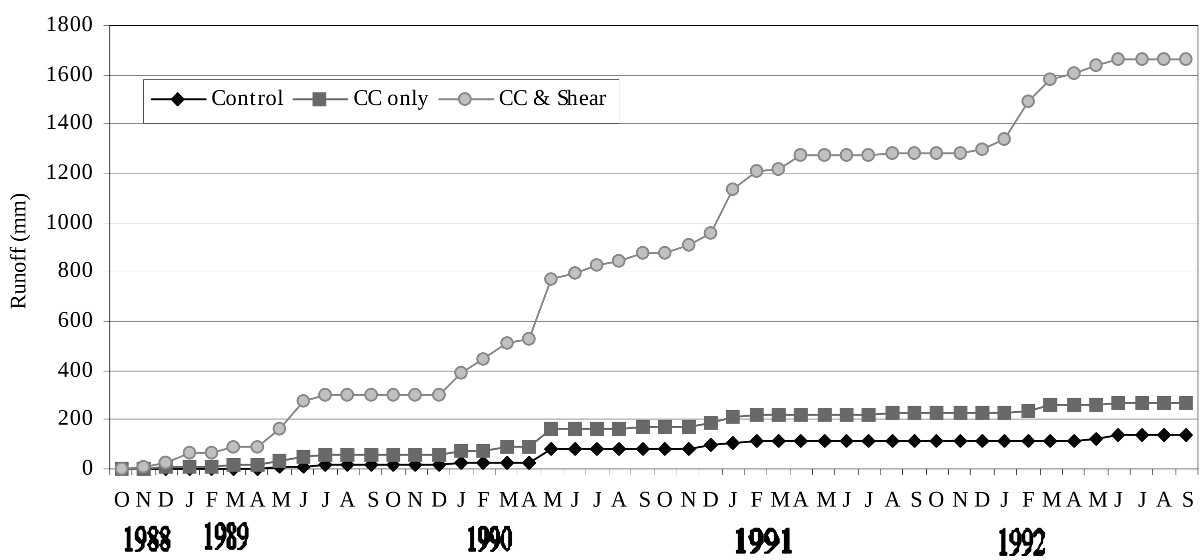

Figure 3—Cumulative runoff for three forest treatments at Apple Springs, Texas.

significantly different. By the fourth year, the sheared and control plots were no longer significantly different. Overall, the sheared plot generated about 28 times more sediment than the commercial clearcut plot and 8 times more than the forested plot. About 44, 70, 79, and 54 percent of the total annual sediment loss was produced from the five largest storms for water years 1989, 1990, 1991, and 1992, respectively.

Soil losses decreased over time on the two treatment plots throughout the study period. On the commercial clearcut plot, this was due to rapid vegetative regrowth following harvest, an indication that vegetation is an effective medium in controlling erosion and sediment transport, despite a 10 percent increase in rainfall from the first year to the second. On the sheared plot vegetative regrowth was prevented for the first two years, and sediment losses remained high during this time (figure 2). During the second year following harvest, the 10 percent increase in rainfall might account for the increase in total sediment loss. Vegetation was allowed to regrow during years three and four, and sediment losses declined until by year four in which sediment losses were no longer significantly different from the control plot. Sediment losses were slightly higher on the control plot during the second year. This could be due to the increase in rainfall. Also, a tornado occurred on January 19, 1990 that resulted in about a 50 percent opening in the canopy. Following the tornado, three large storms occurred that resulted increased sediment yield from the control plot. Greater sediment losses were associated with late winter and early spring when rainfall and runoff rates were greatest (figures 3 and 4).

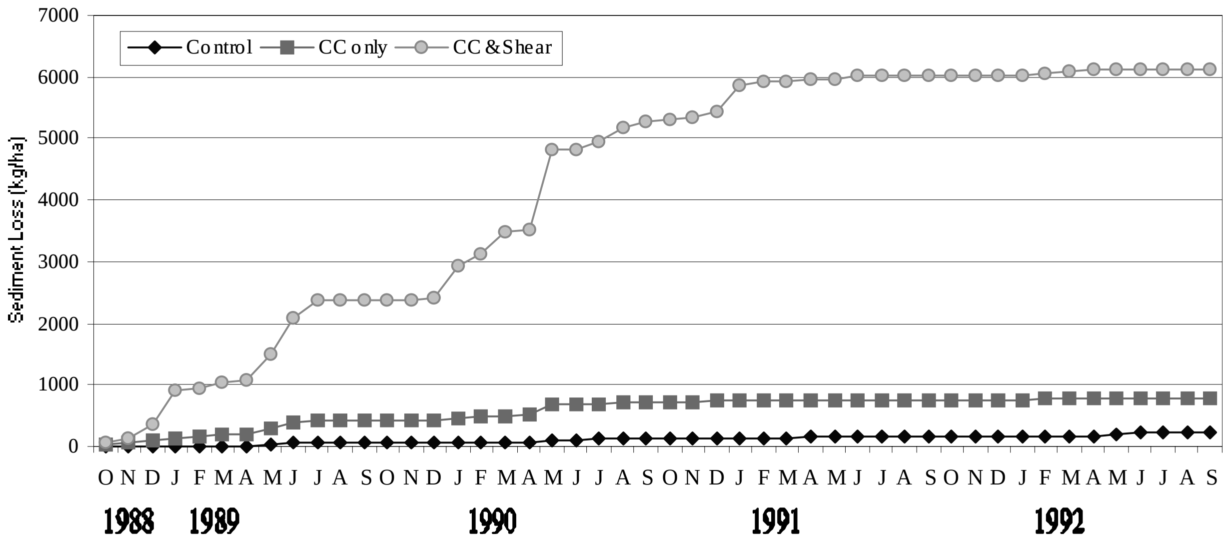

Figure 4—Cumulative sediment loss for three forest treatmnts at Apple Springs, Texas.

Comparison to Other Studies

Based on 16 other studies throughout the southeast USA, Yoho (1980) reported that sediment losses ranged from 2 to 717 kilograms per hectare per year for undisturbed forested watersheds. Sediment losses from the control plot are within the lower end of this range. First year sediment loss for the sheared plot was also within the range of losses reported for other studies in East Texas, 3,462 kilograms per hectare near Etoile, (Chang and others 1982), 2,937 kilograms per hectare near Alto (Blackburn and others 1986), and 306 kilograms per hectare in San Augustine County (Blackburn and others 1990). In this study, first year losses observed from the sheared plot were below those observed near Etoile and Alto, but greater that those observed in San Augustine County.

Several studies have also reported that about 3-4 years are required for sediment losses from sheared plots to return to observed levels on undisturbed areas in the southeast (Blackburn and others 1986; Blackburn and others 1990; Miller 1984). In this study, losses were no longer significant by year four. This period could have been shorter had vegetation regrowth not been prevented during the first two years of the study.

Sediment Estimates

The Universal Soil Loss Equation (USLE) was employed to estimate average sediment losses for the study plots during the study period. The equation estimates sediment A = RKLSCP in which the six factors are related to rainfall, soil, slope length, slope steepness, vegetation/management, and conservation practices, respectively. The C-factor employed was based on values observed for East Texas forests (Chang and others 1982) as they were found to be the most accurate estimates for the East Texas environment (Chang and others 1992). However, the C-value for the sheared plot during the last two years was obtained from Wischmeier and Smith (1978) to account for vegetation regrowth. Thus the long-term C-value for the sheared plot was estimated by averaging the C-values from these two sources. Values of KLSP were based on the standard procedure given by Wischmeier and Smith (1978). R-values were obtained by using the standard Wischmeier and Smith (1978) procedure along with eight other shortcut models developed in various regions (table 2). The standard EI_{30} (kinetic energy x 30 minute intensity) method for calculating R-values requires rainfall intensity information for all runoff-producing storms. This information may not be available and calculations are tedious. If the shortcut methods, generally using annual rainfall to correlate with EI_{30} values, can provide satisfactory estimates, then the use of USLE would be greatly facilitated for stations with only total rainfall.

Estimating sediment losses using R-values obtained from Wischmeier and Smith's (1978) long-term average (US Agricultural Handbook No 537) resulted in about a 143 and a 118 percent overestimation of sediment losses for the shear and commercial clearcut plots, respectively (table 3). However, the two shortcut models developed in the United States (Models 4 and 9) provided sediment estimates for these two plots within 23 percent of those from the observed values. Also, reasonable estimates for these two sites could be obtained from the two models developed in the two tropical regions (Models 3 and 5) with errors less than 50 percent. All estimates by these four models of sediment losses for the forested plot resulted in greater percent errors than for the treatment plots. Because of the relatively small magnitudes of losses from forested areas, these errors are of less concern.

Element Losses

Concentrations of elements were generally below USEPA surface water quality standards and not significantly

Table 2—Ten different models for calculating R-values (metric ton m/ha/hr per yr) for the USLE

Model	Location	Reference
1 $R = [\Sigma^N \Sigma^M (EI_{30})]/(100N) * 1.735$	United States	Wischmeier and Smith (1978)
2 $R = 0.5\,(P) * 1.735$	West Africa	Roose (1975)
3 $R = (9.28(P) - 8838 \times I30) * 0.001$	Malaysia	Morgan (1974)
4 $R = 0.276\,P \times I30 \times 0.01$	United States	Foster and others (1981)
5 $R = (38.46 + 3.48P) \times 0.1$	Hawaii	Lo and others (1985)
6 $R = (0.264 * ((\sum_{i=1}^{12} p_i^2)/P)^{1.50})$	Morocco	Arnoldus (1977)
7 $R = (0.04830P^{1.610}) * 0.1$	United States	Renard and Freimund (1994)
8 $R = (587.8 - 1.219P + 0.004105P^2) * 0.1$	United States	Renard and Freimund (1994)
9 $R = (0.07397 * ((\sum_{i=1}^{12} p_i^2)/P)^{1.847}) * 0.1$	United States	Renard and Freimund (1994)

Note: E = storm kinetic energy (metric ton-m ha^{-1} cm^{-1}), I_{30} = maximum 30 minute storm intensity (cm hr^{-1}), I30 = maximum annual maximum 30 minute rainfall intensity (assumed to be 75 mm hr^{-1}), P = mean annual rainfall (1989-1992) in mm, p_i = mean monthly rainfall (1989-1992), N = number of years, and M = number of storms in each year.

Table 3—Observed and estimated average sediment losses (kg/ha/yr) by the USLE with R-values obtained by nine different models in Apple Springs, Texas

	Forest		Clearcut		Shear	
Source	Loss	Diff[a]	Loss	Diff[a]	Loss	Diff[a]
Observed	55	0	198	0	1,533	0
Estimated						
Model 1	37	-33	431	118	3,729	143
Model 2	54	-1	639	223	5,520	260
Model 3	10	-83	113	-43	976	-36
Model 4	13	-76	152	-23	1,316	-14
Model 5	22	-59	264	33	2,278	49
Model 6	68	23	799	303	6,903	351
Model 7	23	-57	276	39	2,385	56
Model 8	27	-51	319	61	2,760	180
Model 9	14	-75	160	19	1,381	-10

[a]Percent difference where diff = ((obs-est)/obs)*100

Table 4—Mean concentrations (mg/L) and mass losses (g/ha) for 17 elements in the study area for water years 1989-1992[a]

	Mass Losses[b]			Concentrations[b]		
Parameter	Control	Clearcut	Shear	Control	Clearcut	Shear
PO_3	28.46 A	35.76 B	194.52 C	2.92 A	3.44 A	2.61 A
NO_3	3.11 A	4.44 A	42.77 B	0.31 A	0.29 A	0.29 A
NO_2	1.32 A	6.95 AB	10.18 B	0.09 A	1.52 A	0.19 A
NH_4	38.41 A	76.77 B	264.48 C	3.16 A	3.25 A	2.53 A
TKN	99.90 A	123.50 B	448.60 C	5.71 A	5.13 A	4.26 A
K	45.41 A	85.64 A	347.38 B	5.73 A	6.74 A	7.55 A
Cl	208.20 A	253.10 A	1331.80 B	15.57 A	15.42 A	15.34 A
Na	124.40 A	204.51 A	730.12 B	21.07 A	16.92 A	10.91 A
Ca	36.25 A	55.98 A	212.86 B	3.43 A	3.72 A	3.12 A
Mg	44.20 A	43.93 A	168.78 B	2.17 A	2.42 A	2.49 A
Al	4.35 A	6.03 A	49.98 B	0.25 A	0.45 A	1.20 A
Mn	7.20 A	7.74 A	18.92 A	0.01 A	0.26 A	0.27 A
Fe	8.30 A	15.39 A	53.90 B	0.37 A	0.61 A	0.49 A
Zn	23.37 A	42.59 A	105.31 B	0.62 A	1.38 A	1.61 A
Cu	2.19 A	4.25 A	30.45 B	0.28 A	0.27 A	0.36 A
SO_4	188.00 A	243.20 A	993.70 A	26.05 A	20.65 B	12.90 B
HCO_3	325.00 A	543.00 A	957.60 B	45.29 A	55.43 B	38.08 A

[a] Nutrient parameters (PO_4, NO_3, NO_2, NH_4, and TKN) were only measured during water years 1989 and 1990.
[b] Mean values with different letters in a given year are significantly different at $\alpha \leq 0.05$.

different between treatments (table 4). This is due to the dilution effect of greater runoff volume from the treatment plots. However, when concentrations are converted to mass per unit area, elements were found to be different between treatments. Mass losses in grams per hectare were greater from the sheared plot than from the commercial clearcut or the control (table 4). Losses of sodium (Na), chloride (Cl), Calcium (Ca), magnesium (Mg), and aluminum (Al) were especially high. Elements were generally not significantly different between the control and the clearcut plot. However, nutrient parameters such as ortho-phosphorus ($PO_{4)}$, ammonia ($NH_{4)}$, and total Kjeldahl nitrogen (TKN) were significantly greater on the commercial clearcut plot than the control plot.

A comparison of element losses by water year illustrates a general attenuation trend with time. Losses of elements such as Na, Cl, Ca, Mg, and Al were greater from the sheared plot than the control in water year 1989 and 1990. After regrowth of vegetation, only Na and Cl losses remained higher on the sheared plot. Sodium losses following shearing in other East Texas studies were 343 grams per hectare (Blackburn and others 1986) and 380 grams per hectare (Muda and others 1989), much lower than losses observed in this study, 730 grams per hectare. Higher rates of export of Na and Cl would be expected from a saline soil. Vegetative regrowth resulted in reduced rates of Ca and Mg export.

CONCLUSION

Harvesting and mechanical site-preparation greatly reduced evapotranspiration, disturbed soil structure, and increased soil moisture content, resulting in greater runoff volumes and losses of sediment, nutrients, and elements. However, erosion problems did not seem to be serious enough to adversely affect land productivity. Following regrowth of vegetation, losses decreased dramatically until by the fourth year following treatment no differences were observed between the treatments and the control. Neither treatment plot was reforested by artificial means, yet after two years of vegetation regrowth, runoff volumes and sediment losses were no longer different from the undisturbed forest plot. Wischmeier and Smith's (1978) long-term average R-value for the USLE overestimated annual sediment yield for the study period. Two shortcut models developed in the United States for estimating the rainfall factor resulted in more accurate predictions and are good substitutes for the EI_{30} factor in the study area.

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THE BOTTOMLAND HARDWOODS OF THE HATCHIE RIVER, THE ONLY UNCHANNELIZED MISSISSIPPI TRIBUTARY

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Abstract—Documenting the natural condition of the floodplain forests of Mississippi River tributaries becomes ever more elusive as cultural alterations continue to obscure their “original” character. The 4,532 hectare Hatchie National Wildlife Refuge (HNWR) in West Tennessee provides the best-available opportunity to document the floodplain forests that once flourished along the major tributaries of the Mississippi Embayment. Of five major Mississippi tributaries in Tennessee, the Hatchie is the only one that remains unchannelized. Characterizing these “original” floodplain forests was the purpose of this study.

Forest cover types were classified according to species and soil-site relationships. Since these poorly drained soils do not have distinct pedogenic horizons, the single determinant used for distinguishing soil types was depth to gleying (DTG). Six DTG classes were used to delineate soil drainage/tree species relationships. The tree species comprising the forest cover types were classified as “indicator” or “plastic” based on their apparent affinity for specific ranges in DTG. Indicator species were restricted to specific topographic and soil conditions while the plastic species were found on a wide variety of topographic and soil conditions.

INTRODUCTION

Of the five major Mississippi tributaries in West Tennessee all except the Hatchie have been channelized to prevent flooding and/or enable farming. Where successful, this process destroyed the original wetland condition. This major alteration of the bottomland hydrology over much of the Mississippi Embayment has caused serious disruption of both wildlife habitat and forest productivity. Current management options being considered include returning the channelized tributaries to their original channels.

Although the Hatchie continues to follow essentially its natural course, the composition and structure of floodplain forests have been altered by agricultural clearing, siltation, and “high grading” that has removed commercially valuable trees leaving trees of lesser value to restock the area. Only on the Hatchie National wildlife Refuge (HNWR) (established in 1962) are there remnant examples of the character of the “original,” pre-historic forests. Historically, these sites supported high quality forests that were widely distributed over the Mississippi and tributary river bottomlands. However, sedimentation, land clearing, and channelization have greatly reduced both the acreage in, and stature of, this resource (Turner and others, 1981). The composition and character of the original forest communities that once dominated these floodplains were largely controlled by the ability of component species to tolerate various degrees and periods of inundation and soil saturation. The first bottoms usually had standing water during part of the year followed by varying degrees and depths of soil drainage.

Since the early 1800’s, changing land uses in the alluvial valleys of the Mississippi Embayment has resulted in a rapid decrease in bottomland hardwood forest cover types (Sternitzke, 1975 and 1976). As early as 1818, these fertile bottomlands were cleared for cotton production. By 1825 the region had developed into an important cotton producing area. Most of the well drained sites adjacent to the river were being cleared while the frequently flooded bottoms remain in forest (Sternitzke, 1955).

Again in the 1960’s large areas of bottomland forests were cleared for agricultural crops, especially soybeans. This high-return crop was well-suited to these productive sites. Sedimentation, channelization, and beaver impoundments have further deminished both the acreage and quality of the bottomland forest resource (Sternitzke, 1955 and Wells and others, 1974). Between 1950 and 1971, the acreage in bottomland hardwoods decreased by one-fourth in the southeast.

Sedimentation from the eroding uplands continues to degrade the bottomland hardwood resource. The soils of West Tennessee are primarily derived from loess, and are highly erodible. Poor agricultural practices were noted as early as 1860 and continued for more than a century. Sedimentation has caused increased flooding due to impaired drainage through deposition in the floodplains and channels (U.S.D.A., 1977). However, in the last decade there has been a significant improvement in the soil-loss problem in West Tennessee, largely through no-till agricultural practices (from 14.1 tons per acre per year in 1977 to

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7.1 tons per acre per year in 1992 according to the National Resource Inventory). Channelization, levees (both natural and artificial), and siltation have created a habitat that is well suited for beavers, whose impoundments have caused high mortality in some of the last remaining bottomland forests (Byford, 1974).

Trends in conversion to agronomic crops have changed over the past decade primarily due to abandonment of agricultural lands. Although bottomland forest acreage is now increasing (Tennessee Agricultural Statistics, 1980-1982, and 1987-1991), their composition and character has been greatly altered.

According to current definitions, much of the original bottomland hardwood acreage could have been classified as "wetland." Wetlands have recently been recognized as among our most valuable and important ecosystems. Wetlands are transition zones typically found between open waters and land resources. These "in-between places" provide a setting for the dynamic interactions that occur where terrestrial and aquatic systems meet, which make wetlands ecologically valuable (Jensen, 1988). The continuing loss of these diverse transition zones is a major ecological concern.

OBJECTIVES

The objectives of this study were:

(1) to characterize the "natural" bottomland hardwoodre source on a section of a major Mississippi tributary in West Tennessee that remains relatively undisturbed,

and

(2) to determine the relationships between soil-site properties and forest cover types of the Hatchie water shed.

THE STUDY AREA

The Hatchie River is a drainage system for southwestern Tennessee. Its headwaters drain north-central Mississippi before entering Tennessee along the Hardeman-McNairy county line. It flows in a northwest direction through Hardemen and Haywood counties, finally forming the border between Tipton and Lauderdale counties before entering the Mississippi River approximately 56 miles north of Memphis.

The bottomland soils are Entisols (Soil Survey Staff, 1975). Due to their recent development, they do not have distinct pedogenic horizons (Buol and others, 1973). Depth to redoximorphic features such as redox concentrations, redox depletions and reduced matrix (gleying) were the soil properties used to distinguish between different soils in these broad floodplains. The alternating bands of grey/brown or "gley horizons" are indicative of anaerobic conditions caused by saturation most of the year. This prevents the oxidation reactions that impart the reddish color characteristic of most better drained soils.

The Hatchie National Wildlife Refuge (HNWR) is located near Brownsville, Tennessee. It extends approximately 40 km in an east-west direction along the Hatchie River floodplain. This area contains remnants of the only "natural" forests to be found on a major Mississippi tributary in Tennessee. Although siltation from poor farming practices on adjacent uplands has modified site conditions, these forests approximate the "original" or "natural" condition of tributary floodplain vegetation.

STUDY METHODS

Only sites considered to be relatively "undisturbed" were selected for characterizing "natural" forest conditions. Prior to land acquisition for the HNWR, approximately one-half of the forest land had been disturbed by fire, grazing, and/or timber cutting. Only 1,214 ha or approximately one-third of the total Refuge acreage was considered suitable for this study.

Compartment maps of the Refuge (scale of 1/24,000) were used to locate suitable study areas. Sample points were located every 100 m along lines 800 m apart; the first line was randomly located. Any portion of a transect within 400 m of a major disturbance, such as powerlines, highways, or drainage canals, was eliminated. Small adjustments were made to keep the vegetation tallied at each sample location completely within a topographic drainage class. A total of 127 plots was established along 12 transects.

Soils and vegetation were sampled at each sample location. Topographic position and evidence of abnormal flooding were noted. Depth to, and degree of development of reduced matrix (gleization) were used to distinguish different soils. Soil samples were collected from the 0 to 30 cm, 30 to 60 cm, and 60 to 120 cm depths for laboratory analysis to determine pH, K and P levels. Depth to gleying (DTG) was determined using a soil auger.

Arborescent vegetation was sampled using a 2.5 m^2/ha prism. Crown position, diameter breast height (DBH- at 1.3 m ground), and total height were estimated for each "count" tree. DBH and total height estimates were periodically checked using a diameter tape and an Abney level, respectively. Each tree was assigned to a crown class as follows; dominant, codominant, intermediate, and overtopped (Smith, 1962). Dead trees were noted with comments on the gap size their death created. Abundance and height were determined for understory trees and shrubs (between 1 and 4 m in height).

The arborescent vegetation of the study area was characterized for each of six DTG classes. DTG Class 1 represented the poorest drainage condition with mottling apparent in the surface soil. As class number increased mottling was progressively deeper and surface horizons were better aerated. These DTG classes and the soil series they represent were:

Class	Depth-to-gleying	Mapped as
1	Surface gleying	Waverly
2	> 0 but < 15 cm	Waverly
3	15 to 30 cm	Falaya
4	30 to 45 cm	Falaya or Collins
5	45 to 60 cm	Collins
6	60 to 120 cm	Collins or Vicksburg

Characteristics of the four major soil series present were (Brown and others, 1973, 1978; Flowers, 1964):

1) Waverly series - poorly drained soils in the lowest part of the floodplain (coarse-silty, mixed, acid, thermic Typic Fluvaquents).
2) Falaya series - better drained soils on flats and ridges (coarse-silty, mixed, acid, thermic Aeric Fluvaquents).
3) Collins series - moderately well-drained soils on narrow ridges that follow stream channels (coarse-silty,mixed, acid, thermic Aquic Udifluvents).
4) Vicksburg series - well-drained soils on the highest ridges (coarse-silty, mixed, acid thermic Typic Udifluvents).

Soil pH, K and P were analyzed on 273 soil samples from 91 plots by the University of Tennessee Agricultural Extension Service Soil Testing Lab in Nashville. Correlation coefficients and their corresponding probabilities were calculated using SAS (1985). Only coefficients significant at p = 0.05 and lower were used in soil/site - forest cover correlations.

RESULTS AND DISCUSSION

Field sampling revealed little evidence of pedogenic horizon development in soils that underlie the wide, nearly level floodplain of the Hatchie River. These Entisols developed in alluvium and are characterized by an ochric epipedon.

Of the 127 plots sampled, 39 were on soils of the Waverly series, 58 were on Falaya soils, 26 were on Collins and 4 were on Vicksburg. The well drained sites were on natural levees immediately adjacent to the Hatchie River while poorly drained sites were in sloughs and swamps away from the river (generally in old river channels and ox-bow lakes) (figure 1).

Forest cover types were segregated along a soil aeration gradient which was reflected by DTG. Overstory trees and woody understory vegetation were characterized for each DTG class. Figure 1 summarizes the relationship between topographic position, DTG, and overstory trees. Some

Overstory	A.Beech* Yellow poplar* White oak* Sweetgum Swamp Chestnut Oak Cherrybark Oak	Sweetgum Cherrybark Oak* Willow Oak Swamp chestnut Oak Water Oak Silver Maple Swamp Hickory Shagbark Hickory*	Sweetgum Willow Oak Overcup oak Swamp Hickory Baldcypress Silver Maple Chestnut Oak	Overcup oak* Baldcypress* Willow Oak	Sweetgum Willow oak Cherrybark Oak Swamp Chestnut Oak Overcup oak* Swamp Hickory Water Oak Pin Oak	Sweetgum Cherrybark Oak Swamp chestnut Oak Willow Oak Shagbark Hickory* Water Oak Swamp Hickory Mockernut Hickory*	Tupelo gum* Baldcypress Overcup Oak	Sweetgum Swamp Chestnut Oak Water Oak Shagbark Hickory* Cherrybark OakShumar-d Oak Mockernut Hickory* Yellowpoplar A.Beech	Sweetgum CherryBark Oak Swamp Chestnut Shagbark Hicory* Water Oak Mockernut Hickory* Blackgum*
Understory	A.Holly Pawpaw Estern Hophorn-beam Stiff Dogwood Cane	A.Elm A.Hornbeam Sweetgum Deciduous Holly Swamp Chestnut Oak	Planer Tree A.Elm A. Hornbeam Sweetgum Deciduous Holly	Paner Tree Deciduous Holly	Planer tree A. Hornbeam A.Elm Sweetgum Deciduous Holly	A.Elm A.Hornbean Grapevine Greenbriar Sweetgum Swamp Chestnut Oak Shagbark Hickory*	Buttonbursh Planer Tree Virginia Willow	A. Hornbeam Sweetgum Grapevine Greenbriar Shagbark Hickory* SwampChe-stnut Oak Pawpaw	A.Hornbeam A.Elm Swamp Chestnut Oak Sweetgum Shagbark Hickory* Cane

*Indicator Species

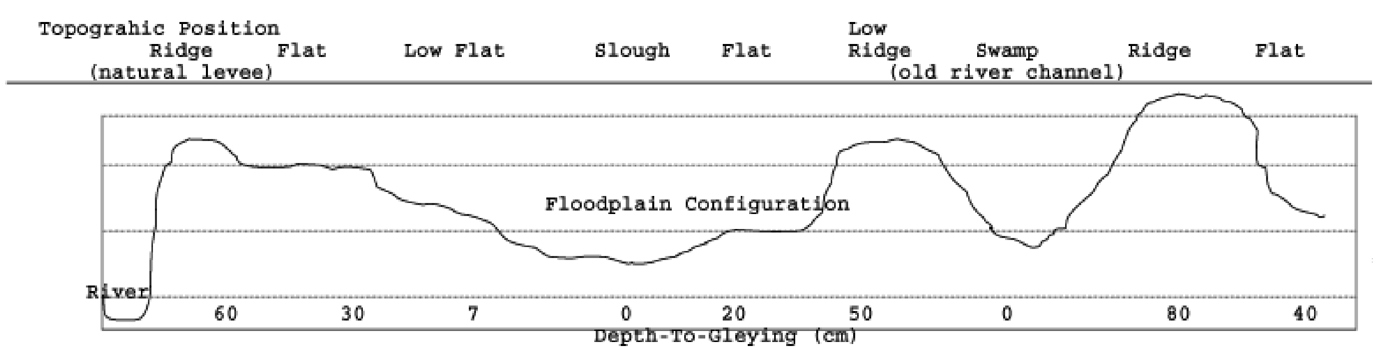

Figure 1—Overstory and understory species and topographic position in the Hatchie Wildlife Refuge.

species were found only on specific DTG classes while others were very plastic, occurring on all or most DTG classes. The site-specific trees are good indicators of soil drainage and, in turn, soil series. Indicator species and their associate DTG classes and soil series are:

TUPELO gum DTG = 0 cm (Surface gleying) Soil Series = Waverly

The presence of tupelo gum (*Nyssa aquatica* L.) was indicative of swamp areas where gleying occurred at the ground surface (DTG 0 cm). While surface water may disappear in areas supporting tupelo gum during the midsummer and fall, surface soil moisture remains at or near saturation throughout most of the growing season. These soils are commonly called "mucks."

BALDCYPRESS DTG = 0-20 cm: Soil Series = Waverly

As soil aeration improved, tupelo gum was replaced by bald-cypress (*Taxodium distichum* (L.) Rich). This intolerant conifer is unique in that it is maintained in and along ox-bow lakes and is favored by frequent flooding which suppresses its more shade- tolerant competition. In bald-cypress groves, DTG was commonly from just below the surface to 20 cm. This "deciduous evergreen" grew best on "mucks" but occurred on a wide range of soil draniage conditions. In the absence of frequent flooding, baldcypress was replaced by overcup oak (*Quercus lyrata* Walt.).

OVERCUP oak DTG = 0-20 cm: Soil Series = Waverly

While overcup oak was relatively plastic in its occurrence (DTG 0 to 20 cm), it was most common on areas where flooding was annual but not continuous. Along with tupelo gum and baldcypress, overcup oak was one of the most flood-tolerant species. It was common in sloughs and swamps. However, it grew better on low-lying clays or silty clay flats in first bottoms and the terraces of larger streams.

TERRACE hickories DTG = 20-50 cm: Soil Series = Falaya & Collins

The terrace hickories, shagbark (*Carya ovata* (Mill.) K. Koch) and mockernut (*Carya tomentosa* (Poir.) Nutt.), marked a transition from low flats (DTM = 7 cm) to flats and low ridges (DTG = 20-50 cm). Shagbark hickory was the predominant species, adapting successfully to a variety of soil conditions. Mockernut hickory, a common associate of shagbark, was found on somewhat better-drained sites than those favoring shagbark. Soil conditions favorable to mockernut hickory ranged from deep, fertile surface horizons to poorly drained loams with a fragipan. Both shagbark and mockernut hickory were common on dry sites and ridges where swamp chestnut oak (*Quercus michauxii* Nutt.) and water oak (*Quercus nigra* L.) were the predominant species.

Where shagbark and mockernut hickory were a significant component of the overstory, understory vegetation included seedlings of shagbark hickory and American elm (*Ulmus americana*, L.) and swamp chestnut oak saplings.

BLACKGUMDTG = 40 cm: Soil Series = Falaya & Collins

Blackgum (*Nyssa sylvatica* Marsh.) was not a dominant species in any of the forest associations identified but did reflect specific drainage conditions. It was consistently found on flats where DTG was 40 cm or greater. It grew best on well-drained, light textured soils on low ridges of second bottoms or on high flats of silty alluvium. On upland sites loams and clay loams produced the best growth. Where blackgum was common in the overstory, American elm and American hornbeam (*Carpinus caroliniana* Walt.) were frequent understory components.

AMERICAN BEECH - yellow-poplar - white oak DTG = 60-80 cm: Soil Series = Vicksburg

The most consistent indicator species for the better-drained soils were American beech (*Fagus grandifolia*, Ehrh), yellow-poplar (*Liriodendron tulipfera* L.), and white oak (*Quercus alba* L.). These hardwoods marked a shift from flat, wet sites to high well-drained ridges. Yellow-poplar and white oak were especially indicative of improved soil drainage. Soils were usually alluvial, deep, fertile, moist, and highly productive.

Common understory associates included planer tree (*Planer aquatica* (Walt.) J.F. Gmel.) and American hornbeam which were replaced on drier sites by a dense understory of stiff dogwood (*Cornus foemina* Mill.), pawpaw (*Asimina triloba* (L.) Dunal), eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), and American holly (*Ilex opaca* Ait. f. *opaca*).

Although these high ridges contained the more valuable commercial species, the average stand basal area progressively decreased as depth to gleying increased. This was due in part to competing vegetation other than trees; approximately 50 percent of these sites had extensive encroachment from vines.

A comparison of the forest types found on first bottoms of the HNWR with the Society of American Foresters (SAF) Forest Cover Types for the Southern Forest Region revealed that the following were represented: 1) baldcypress (101), 2) baldcypress-tupelo (52), and yellow-poplar-white oak-northern red oak (102) (Eyre, 1980).

The terrace hickories presented a unique situation. Although they do not comprise a designated SAF forest cover type, their silvical characteristics suggest that their occurrence in river bottoms is not unusual. According to Burns and Honokala (1990), shagbark and mockernut hickory grow best in humid climates and tolerate a wide range in soil-site conditions. Common associates of the terrace hickories include indicator species such as tupelo gum, yellow-poplar, blackgum, white oak, and American beech plus a number of bottomland hardwood species.

CONCLUSION

This study revealed well-defined relationships among native tree species, soil series, topography, and soil drainage classes in the first bottom of the Hatchie River. These include:

1) The most poorly drained sites were the “mucks” found in swamps and sloughs. Topographically these were generally the lowest points with gleying at the ground surface - soils were of the Waverly series. Indicator species included baldcypress and tupelo gum. Similar associations were found in ox-bow lakes.
2) Low flats, flats, and low ridges provided better-drained sites. Depth to gleying varied from 20 to 50 cm indicating better drainage of the surface horizons. These better drained soils belonged to the Falaya series. Common indicator species included the terrace hickories and blackgum.
3) The natural levee immediately adjacent to the river provided the best drained site in the first bottom. It was generally the highest feature in the first bottom and had a high sand content that encouraged rapid drainage. These well-drained soils belonged to the Vicksburg series. Indicator species were American beech, yellow-poplar, and white oak. Similar associations were found on former levees along abandoned stream channels and oxbow lakes.

These forest cover - soil drainage relationships provide insight as to the likely character of the “original” floodplain forests that once bordered the mid-continent section of North America’s largest river and its major tributaries.

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